U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

AD-A031 924

An Evaluation of Window Glass for Air Traffic Control Tower Cabs

National Aviation Facilities Experimental Ctr, Atlantic City, NJ

Oct 76

Report No. FAA-RD-76-105

321092

ADA031924

AN EVALUATION OF WINDOW GLASS FOR AIR TRAFFIC CONTROL TOWER CABS

Lee E. Paul
J. Roy Bradley
Donald A. Martin

OCTOBER 1976

FINAL REPORT

Document is available to the public through the
National Technical Information Service
Springfield, Virginia 22151

Prepared for

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

Systems Research & Development Service

Washington, D.C. 20590

NOTICE

Technical Report Documentation Page

1. Report No. FAA-RD-76-105	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle AN EVALUATION OF WINDOW GLASS FOR AIR TRAFFIC CONTROL TOWER CABS		5. Report Date October 1976
		6. Performing Organization Code
		8. Performing Organization Report No. FAA-NA-76-13
7. Author(s) Lee Paul, J. Roy Bradley, Donald A. Martin		
9. Performing Organization Name and Address Federal Aviation Administration National Aviation Facilities Experimental Center Atlantic City, New Jersey 08405		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 081-431-120
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590		13. Type of Report and Period Covered Final March 1974 - August 1975
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Seven samples of commercially available glass were evaluated to determine their suitability for use in air traffic control tower cabs. Spectral transmissivity measurements were made on each sample for all wavelengths in the visible spectrum. A small experimental tower cab was constructed near the NAFEC airport, and controllers evaluated the samples in the tower cab under day, night, dawn, and dusk viewing conditions. The controller ratings were analyzed and evaluated in terms of the optical transmissivity of the samples and the type of window; i.e., single pane and double pane. There were differences in the ratings of the samples, and the relative merit of the samples depended, in part, on the time of day the ratings were made. An unexpected factor in the ratings was the appearance of internal reflections in the double pane windows at night.

COLOR ILLUSTRATIONS REPRODUCED IN BLACK AND WHITE

17. Key Words Air Traffic Control Tower Cab, Windows, Visibility, Human Factors	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 45	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

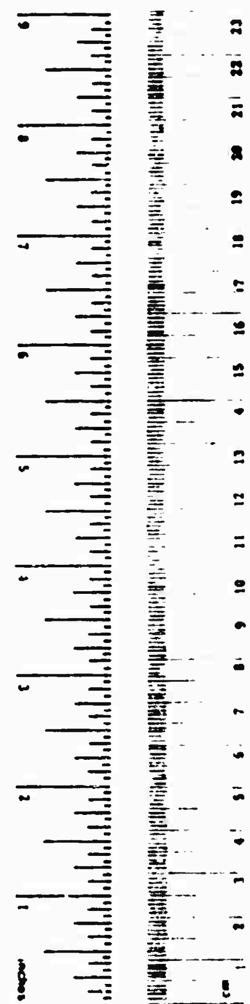
A number of people made significant contributions to this study. Gerard Spanier and Frank Baldwin, Jr., conducted the transmissivity analysis using the Gamma Spectroradiometer. Bill Donaghy, Joe Yugovich, and Rudy Antonio performed above and beyond the normal course, moving glass panels and scheduling and assisting subjects at all hours of the day and night. Don Eldredge provided invaluable assistance in guiding the raw data onto the right coding forms, through the appropriate statistical model, and in and out of the computer.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

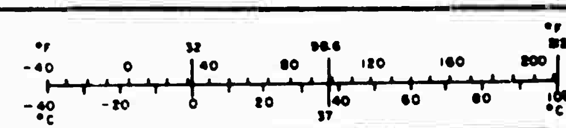


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

PURPOSE.

The purpose of this study is to respond to a request for a research and development effort that would lead to the establishment of a national standard for air traffic control (ATC) tower cab glass. This request was initiated by a desire to utilize the thermal insulation and glare reduction properties available in various glass products to the maximum feasible extent in new Federal Aviation Administration (FAA) towers. Of special interest was a glass, presently in use by the Air Force for towers, that is composed of two 1/4-inch panes separated by a 1/2-inch airspace. The Air Force window has one pane that is heat absorbing, and the visible transmittance is approximately 67 percent. To quote the request; "The primary object of this effort is to establish an allowable illuminance which may allow the FAA to use heat absorbing and/or tinted glass."

BACKGROUND.

The specification of maximum permissible filtration would be straightforward if it were possible to define the worst-case target and the viewing conditions under which the controller must be able to detect it. It became apparent, early in this investigation, that the visual environment of the tower cab is indescribable--or at least undefinable. The range of brightness the controller may have to deal with in a single day can extend from 10,000 foot-lamberts (snow in sunlight) to 0.00001 foot-lamberts (overcast moonless sky). Visibility is also influenced by atmospheric conditions: rain, falling snow, haze, fog, and smog. In spite of these varying conditions, controllers are expected to detect and identify aircraft in the air and on the surface with and without lights; detect and control special vehicular traffic on the surface; perform a variety of tasks inside the tower, such as monitoring airport surveillance radar (ASR) and airport surveillance detection equipment (ASDE) radars; and operate various keyboards and controls. This range of tasks and conditions must be kept in mind in attempting to arrive at any general solution to the problem at hand.

Since there was nothing to be found in the scientific literature that was directly applicable to the immediate problem, contact was made with the Vision Committee of the National Research Council and this led to some telephone conversations on the nature of the problem with Dr. Conrad Mueller of the Department of Psychology of Indiana University. Dr. Mueller confirmed three basic conclusions that had been tentatively arrived at in the planning of this study:

1. Since the controller's visual task could not be precisely stated, there would be little point in conducting a carefully controlled study in which both the targets and the viewing conditions were precisely measured.

2. There was nothing in the literature directly related to the problem at hand.

3. Having operational personnel evaluate the glass samples under realistic conditions could provide useful information.

An initial analysis of the problem and a method of approach was done by Dr. J. Ludel, in a working paper titled, "Tower Window Glass: Evaluation of Glass Samples" (appendix A). The working paper drew several conclusions relevant to this study:

1. Decreasing the transmissivity of the glass will reduce the visual stimulation reaching the eye and thereby reduce acuity (the ability to see very small objects and to discriminate separate details).

2. Moderate reductions in transmissivity will have only negligible effects while under bright conditions; however, while under dim light conditions, dusk, or heavy overcast, even small reductions in transmissivity will be noticed.

3. All other things being equal, tinted glass which filters out infrared light is preferable, since such glass will tend to reduce overheating of the cab under bright conditions.

4. Other things being equal, tinted glass which markedly filters out light in the blue-green region of the spectrum is to be avoided, since light in that wavelength is most important for night vision.

These conclusions have been incorporated into the present evaluation to the maximum extent feasible.

DISCUSSION

The first step in this evaluation was to select a number of glass samples which represented the range of alternatives. Candidates for consideration had to meet two criteria: first, they had to have reasonable optical and thermal characteristics for possible tower application; and second, they had to be available in quantity, size, and cost, commensurate with tower construction. The latter criterion was responsible to the elimination of "photochromic" glass. Seven samples of glass were selected for the test. Two 3x3-foot pieces of each of the following were purchased:

Sample A - Pittsburg Plate Glass (PPG), 1/4-inch Solar Bronze, 1/2-inch space, 1/4-inch clear.

Sample B - PPG, 3/8-inch clear, 1/2-inch space, 3/8-inch clear.

Sample C - PPG, 1/4-inch Solex, 1/2-inch space, 1/4-inch clear.

Sample D - PPG, 1/4-inch, Solar Cool, 1/2-inch space, 1/4-inch clear.

Sample E - 3/4-inch clear float, single pane.

Sample F - Libby, Owens, Ford (LOF), 1/4-inch heat-absorbing, 1/2-inch space, 1/4-inch clear.

Sample G - LOF, 1/4-inch gray, 1/2-inch space, 1/4-inch clear.

The first phase of this study required spectral transmissivity measurements to be made of each of the two samples of each type of glass with a Gamma Model 3100 Scanning Spectroradiometer.

Copies of the original records are shown in appendix B. The upper line on each chart is a measure of the intensity of a broad spectrum light source, while the lower line is a measure of the same source through the glass sample. The ratio of the two values gives the percentage of transmission for a single wavelength. The average of these ratios is shown in table 1 as "Measured Average Transmission" (column 2). Since the human eye is not equally sensitive to all wavelengths--even in the visible spectrum--a more useful measure of glass transmissivity is based on an average weighted by the effectiveness of each spectral value. The accepted standard for these values is the I.C.I. (International Commission on Illumination) standard shown in appendix C.

The transmissivity values that take the eye's sensitivity into account are shown in table 1 as "Weighted Transmissivity' (column 3). The column headed "Average Daylight" contains the transmissivity reported by the manufacturer where that information is available.

TABLE 1. TRANSMISSIVITY OF GLASS SAMPLES

Sample	1. Average Daylight* (percent)	2. Measured Average (percent)	3. Weighted Average (percent)
A. 1/4-inch Solar Bronze	20	48.6	50.7
B. 3/8-inch clear	83	70.9	73.0
C. 1/4-inch Solex	65	68.6	82.1
D. 1/4-inch Solar Cool	35	31.3	32.7
E. 3/4-inch clear	-	88.9	91.7
F. 1/4-inch heat absorbing	66	65.0	68.0
G. 1/4-inch gray	39	40.0	40.5

*Manufacturers' specifications, where available.

The next phase of this study is concerned with the problem of evaluating the samples in an operational context, determining their suitability for ATC use.

Sample E - 3/4-inch clear float, single pane.

Sample F - Libby, Owens, Ford (LOF), 1/4-inch heat-absorbing, 1/2-inch space, 1/4-inch clear.

Sample G - LOF, 1/4-inch gray, 1/2-inch space, 1/4-inch clear.

The first phase of this study required spectral transmissivity measurements to be made of each of the two samples of each type of glass with a Gamma Model 3100 Scanning Spectroradiometer.

Copies of the original records are shown in appendix B. The upper line on each chart is a measure of the intensity of a broad spectrum light source, while the lower line is a measure of the same source through the glass sample. The ratio of the two values gives the percentage of transmission for a single wavelength. The average of these ratios is shown in table 1 as "Measured Average Transmission" (column 2). Since the human eye is not equally sensitive to all wavelengths--even in the visible spectrum--a more useful measure of glass transmissivity is based on an average weighted by the effectiveness of each spectral value. The accepted standard for these values is the I.C.I. (International Commission on Illumination) standard shown in appendix C.

The transmissivity values that take the eye's sensitivity into account are shown in table 1 as "Weighted Transmissivity' (column 3). The column headed "Average Daylight" contains the transmissivity reported by the manufacturer where that information is available.

TABLE 1. TRANSMISSIVITY OF GLASS SAMPLES

Sample	1. Average Daylight* (percent)	2. Measured Average (percent)	3. Weighted Average (percent)
A. 1/4-inch Solar Bronze	20	48.6	50.7
B. 3/8-inch clear	83	70.9	73.0
C. 1/4-inch Solex	65	68.6	82.1
D. 1/4-inch Solar Cool	35	31.3	32.7
E. 3/4-inch clear	-	88.9	91.7
F. 1/4-inch heat absorbing	66	65.0	68.0
G. 1/4-inch gray	39	40.0	40.5

*Manufacturers' specifications, where available.

The next phase of this study is concerned with the problem of evaluating the samples in an operational context, determining their suitability for ATC use.

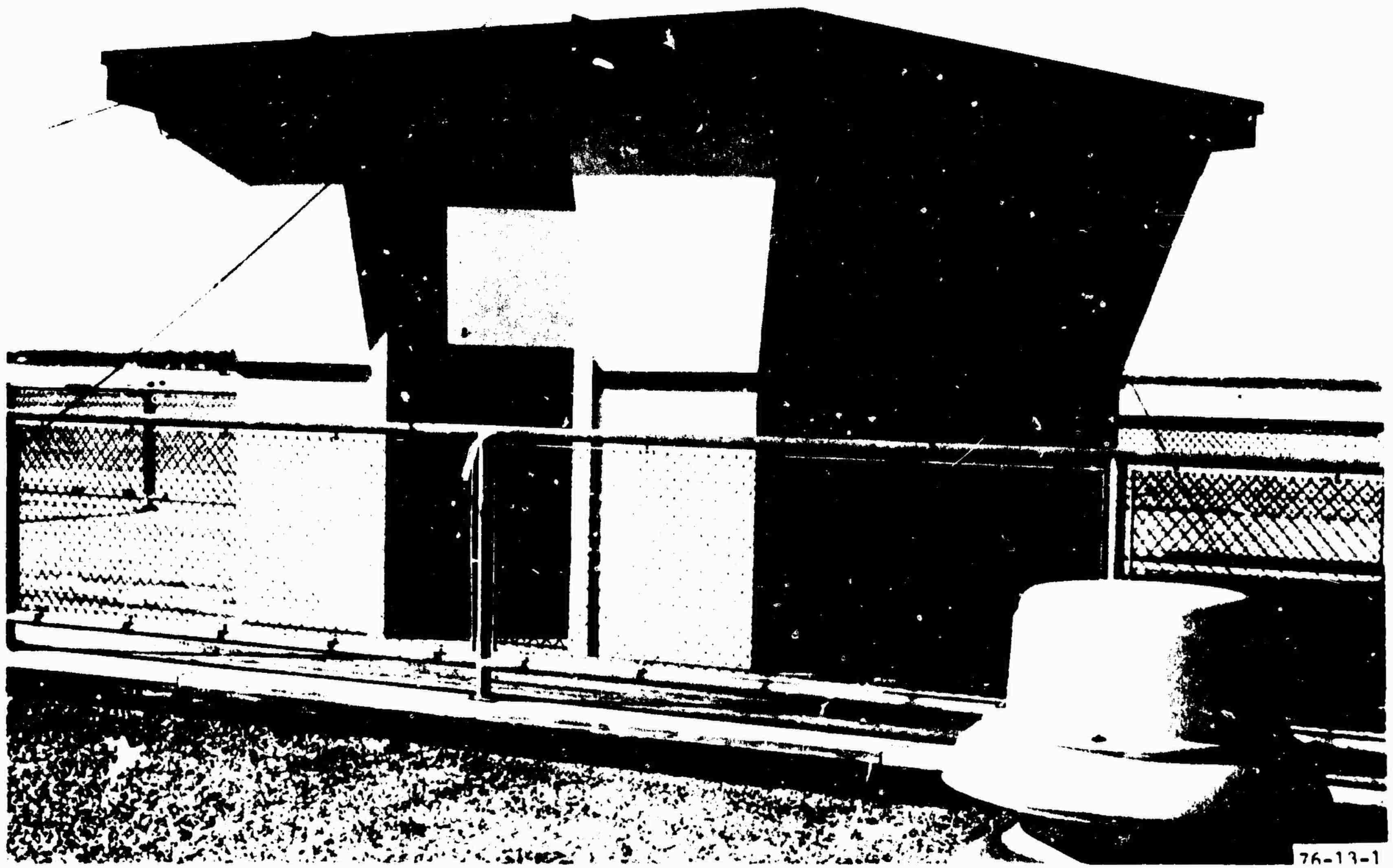


FIGURE 1. MODEL TOWER CAB

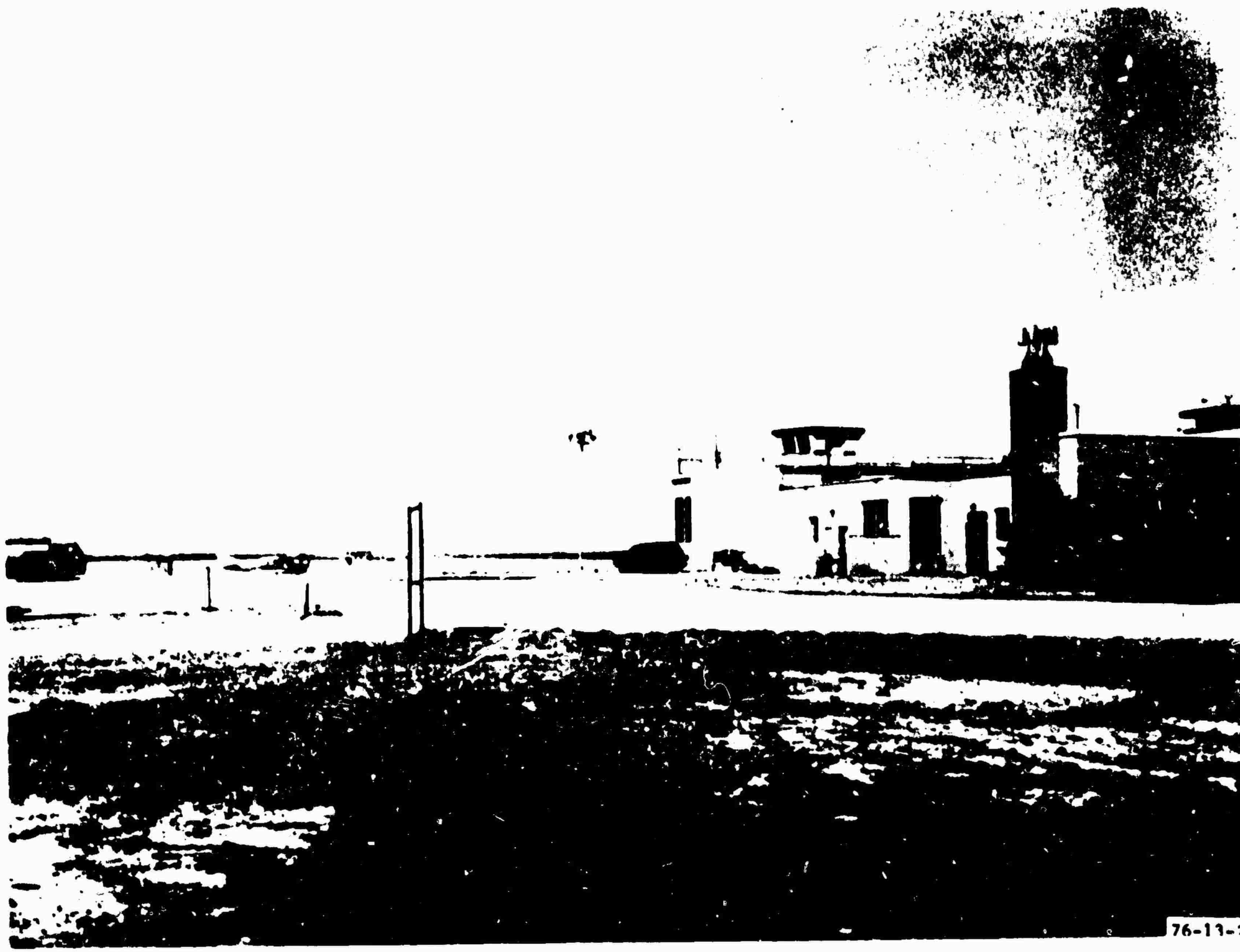


FIGURE 2. MODEL TOWER CAB, SHOWING LOCATION AND SITING

have better insulating value than the glass presently in use and will provide a more glare-free environment for the controllers. The purpose of the test in which you will be participating is to insure that the glass in future towers will in no way interfere with the controllers' performance of their visual tasks.

Your role in this study will be to look through several samples of commercially available glass, under several lighting conditions, and determine which would be satisfactory for use in tower cabs. You will probably make these evaluations under three conditions; dawn or dusk, daylight, and night. Each evaluation should be made considering only that condition of light which prevails at the time. The evaluation will be made as follows: Look at the samples of glass in the test tower. Make observations around the airport, as you would if you were controlling traffic. Then, using the form provided, rate each glass sample.

The tests will be conducted in the small tower built on the observation platform of the Atlantic City Terminal Building (building 250). The tower is reached from the second floor of the terminal.

We welcome any comments you may have about the samples or the conduct of the test.

You have been scheduled to be an observer at the following times:

__/ __, __:__ __/ __, __:__ __/ __, __:__"

The observations are based on the controller's filling out a questionnaire (see appendix D), with the following instructions and response categories:

"Look at the seven glass samples in the tower cab and make observations around the airport as you would if you were controlling traffic from the tower. After you have looked at all samples, rate each one considering whether it helps or hinders the controllers' visual task UNDER PRESENT WEATHER AND LIGHTING CONDITIONS. Please record any comments you may have about the glass or the test situation."

POOR ( ) FAIR ( ) GOOD ( ) VERY GOOD ( ) <u>COMMENTS</u>

It should be noted that the observers were not directed to look at anything special around the airport, that there were no targets set up for them, and that the nature of the differences in the glass samples was not described. The reason is that any structuring of the test situation could create an undue emphasis on one aspect of the total situation, leading the observers, and biasing the results. By allowing each of the 23 controllers to decide for himself what is important, idiosyncratic or unimportant factors should cancel each other out, while factors of general concern will remain.

The questionnaire data were coded as follows: POOR--10, FAIR--20, GOOD--30, VERY GOOD--40. The two questionnaires for each subject made under the same

conditions, i.e., dawn/dusk, day, or night, were averaged together so that there was one combined rating per subject, per glass sample, per lighting condition.

RESULTS

An analysis of variance was conducted on the data to determine which, if any, of the differences were statistically significant. The results of this analysis are summarized in table 2.

TABLE 2. SUMMARY OF ANALYSIS OF VARIANCE

Source	Sum of Squares	DF	Mean Square	F-Ratio	Probability
Between Err.	5524.945	22	251.134		
Time (A)	1767.184	2	883.592	27.971	.001
W/N Err.	1389.958	44	31.590		
Glass (B)	7839.437	6	1306.573	22.711	.001
W/N Err.	7593.887	132	57.529		
A/B (Interaction)	3687.888	12	307.324	8.657	.001
W/N Err.	9371.633	264	35.499		
Total	37174.945	482	77.126		

The analysis shows that there were statistically significant differences in the ratings of the glass samples, that the time of day the ratings were made was a significant factor, and that which glass samples were judged best was, in part, determined by the time of day at which the judgment was made.

Having determined that time, type of glass, and time/glass interaction were significant, Tukey's "Honestly Significant Difference Test," was applied to the averages to determine which differed significantly from the others.

The average ratings for the seven glass samples were: NIGHT-22.5, DAWN/DUSK-25.4, DAY-27.1 (20=FAIR, 30= GOOD). Only the difference between the day and night ratings is statistically significant.

There is also a statistically significant difference between the ratings of the glass samples, showing that the differences in the samples have a real effect on the visual task. Since the interaction between the glass samples

and time of day is also statistically significant, the merit of any sample depends, in part, on the conditions under which it was observed. This is not unexpected; we would not expect the best glass in the sun to be best at night also.

Table 3 gives the average rating for each sample under each of the three lighting conditions.

TABLE 3. AVERAGE RATINGS OF EACH SAMPLE FOR EACH LIGHTING CONDITION

	A	B	C	D	E	F	G	Average
NIGHT	28.1	18.5	18.7	15.9	33.3	20.9	21.1	22.5
DAWN/DUSK	26.3	26.3	26.5	15.2	35.0	26.5	22.2	22.4
DAY	26.5	24.5	30.2	21.7	27.0	29.1	28.5	27.1
AVERAGE	26.0	23.2	25.1	17.6	31.7	25.5	23.9	25.1

The Tukey analysis of these data shows that under night conditions, samples A and E are significantly better than any of the other samples, but not different from each other. Under dawn/dusk conditions, E is best, D is worst, and the difference between E and D is statistically significant, but no other differences are. During daylight, the only significant differences have to do with sample D; it is significantly poorer than samples A, C, F, and G.

When the data in table 3 are plotted (figure 3) in a manner that considers the transmissivity of the samples, certain relationships between the variables are suggested. Except for the daylight condition, there is a relationship between the ratings and transmissivity. The highest rating goes to sample E, with the highest transmissivity, 91.7 percent, the lowest to D, with 32.7 percent. The dawn/dusk condition shows no reversals of this preference for clearer glass, but night conditions show a noticeable reversal with sample A. With a transmissivity of 50.7 percent, it is rated higher than F, C, and B with 68.0 percent, 72.1 percent, and 73.0 percent, respectively.

This apparent inconsistency leads to a point that was made in the "comments" portion of many of the questionnaires, that under nighttime conditions annoying internal reflections were observed in several of the double-pane windows. E, the single pane, did not introduce any reflections and so was rated very high. A, a double-pane unit, also avoided producing internal reflections and was also rated high. The presence or absence of internal reflections was clearly a factor in the nighttime evaluation of the samples.

The daytime evaluation does not seem much affected by the different types of glass. The rating of the poorest daytime sample was better than all but two of the nighttime samples. It seems clear, however, that even under

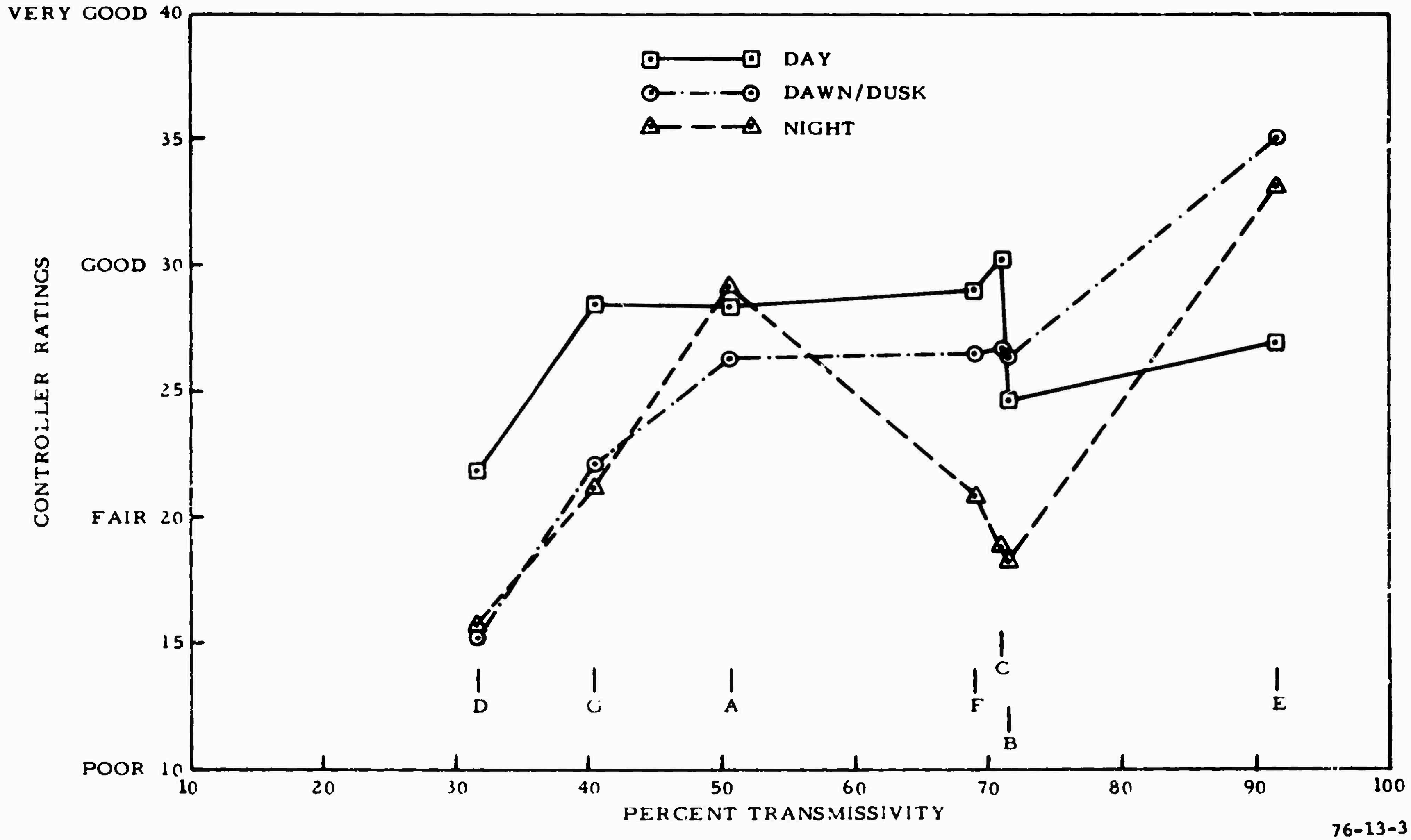


FIGURE 3. AVERAGE RATINGS OF THE GLASS SAMPLES, BY TIME OF DAY, ARRANGED IN ORDER OF INCREASING TRANSMISSIVITY

bright conditions it is possible to have too much filtration, since D, at 32.7 percent, was judged significantly poorer than the samples with moderate filtration, G, A, F, C, and B.

The operational significance of the internal reflections is not clear. Certainly they were visible to the controller observers and could be photographed at night (see appendix E). The extent to which they might confuse a busy ground or local controller, or add to the difficulty of his visual task, can only be conjectured. Small airports are not usually busy at night, and most of the larger airports are using the heavier single-pane windows. We have had no feedback on this phenomenon from the field. (Any application of double-pane tower windows at a high-activity airport should be preceded by an on-site study of the internal reflections. Should the problem prove serious, various coatings could be tried to reduce the reflections.)

The question of what is the maximum permissible filtration is equally difficult to resolve. The conspicuity of objects depends--among many other things--on the contrast between the object and its background. In bright sunshine, contrast ratios are so high that the small reductions brought about by filtration are more than offset by the reduction of strain-producing glare. Under low ambient light conditions associated with dawn, dusk, and night, the effect of filtration depends very much on the nature of the target. Bright lights against a dark background will be seen without difficulty through moderate filtration, but dim or marginal light sources may be lost. Unlighted targets will be lost in total darkness regardless of the presence or absence of a filter, but as darkness descends, the filter will cause them to be lost earlier. Selection of the proper colored filter can actually enhance contrast under certain conditions of fog and haze.

The ideal window would be clear at night and have reduced transmissivity in bright daylight. Phototropic or photochromic glass which possesses the property of darkening under bright conditions and clearing at night was investigated for tower use in 1963, but it was not then, nor is it now, commercially available in the quantities that would be needed. An excellent alternative, the traditional ATC solution to the problem, is the use of Office of Aviation Medicine (AAM) approved sun glasses. Their main advantage is that they are removable when not needed.

The preceding discussion makes it evident that any filtration in tower cab window glass must be a compromise, not as much as might be called for in bright sunlight, more than is necessary at night; from a purely visual standpoint, a less satisfactory solution than the use of sunglasses and transparent window shades. Nevertheless, a modest amount of filtration might produce significant advantages in reducing air-conditioning loads and solar heat radiation in the cab without compromising visibility under any but the most unusual circumstances. The data collected during this study do not provide a definitive answer--given the complexity of the problem, there may not be a simple answer to this question. However, a tower cab glass with a transmissivity of 65 percent or greater would probably not be noticeably less transparent than clear (nominally) glass.

CONCLUSIONS

The above discussion leads to the following conclusions:

1. Solely from the standpoint of the controllers' visual tasks, given the variety of conditions under which they must be performed, clear, single-plate glass does the best job.

2. A moderate reduction in transmissivity will be safe, but not below 65 percent.

3. Internal reflections in the double-pane windows can present a problem at night. This problem could be serious on a large, busy airport with many runway and taxiway lights and a good deal of moving traffic.

BIBLIOGRAPHY

Kirk, Robert E., Experimental Design: Procedures for the Behavioral Sciences, Brooks/Cole Publishing Co., Belmont, Cal., 1968, pp. 88-90.

Stevens, S. S., Handbook of Experimental Psychology, John Wiley & Sons, Inc., New York, 1951, pp. 819.

APPENDIX A

WORKING PAPER, "TOWER WINDOW GLASS:
EVALUATION OF GLASS SAMPLES"

WORKING PAPER

TOWER WINDOW GLASS:

EVALUATION OF GLASS SAMPLES

142-173-120 - ATC TOWER CAB GLASS

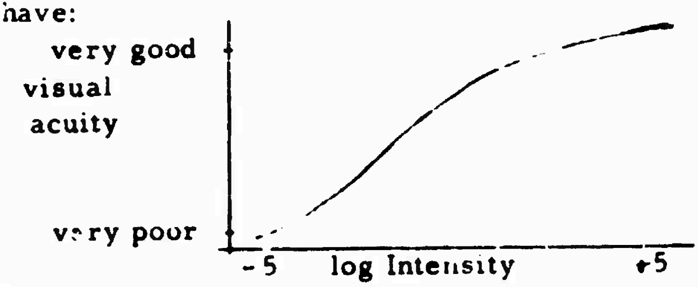
J. Ludel, ANA-230

August 30, 1974

TOWER WINDOW GLASS: EVALUATION OF GLASS SAMPLES

I. Background

There is a long history of studies in the experimental literature indicating that the ability to detect and recognize visual stimuli declines as the illumination level diminishes (e.g., Riggs, L. A. "Visual Acuity", Ch. 11 in C. H. Graham et al., Vision and Visual Perception, Wiley, 1965). While the rate of decline varies among studies, we can generalize the findings as follows: Visual acuity falls off as a function of the log of the intensity of stimulation. Thus, we have:



The introduction of tinted glass to cab towers will reduce the amount of light reaching the controllers within the cab. Thus, the introduction of tinted glass will result in the reduction in the intensity of stimulation. As indicated in the figure above, such a reduction will impair visual acuity and glass with denser tints will more seriously impair acuity than glass with lighter tints. Since we have no measurements of the acuity levels required to successfully execute the tasks of a cab controller, it is not possible to specify the reduction in the intensity of stimulation (and the consequent impairment of acuity) that can be tolerated.

Certain general statements can be made:

a. While it is not possible to specify the amount of acuity impairment which can be tolerated, there can be no doubt that the least possible impairment is preferable;

b. The amount of impairment created by glass of a particular tint will vary as a function of the ambient outdoor illumination. Under bright conditions (e. g., a clear day at noon), a small reduction in the intensity of stimulation may have only a negligible effect on acuity. However, under dim conditions (e. g., dusk or a heavily overcast day), the same small reduction in the intensity of stimulation may have a profound effect on acuity. Reference to the figure above will clarify this point: Small reductions from high illumination conditions (+5 in the figure) result in a minor acuity impairment while small reductions from moderate illumination conditions result in a marked acuity impairment (note the change in slope of the function);

c. All other things being equal, tinted glass which filters out infrared light is preferable since such glass will tend to reduce the overheating of the cab under bright conditions;

d. All other things being equal, tinted glass which markedly filters out light in the blue-green region of the spectrum is to be avoided. Light in the blue-green region is of primary importance to vision under very dim illumination conditions (i. e., rod vision) and filtering out such light can very adversely affect acuity during the period from dusk to daylight.

3

Based on these statements, the following conclusion can be reached: The ideal glass is one whose transmissivity closely approximates that of clear glass in the visible spectrum and whose transmissivity is markedly below that of clear glass in the infrared. It is important to note that knowing the overall visible spectrum transmissivity of a particular glass is not sufficient. Transmissivity data as a function of wavelength should be acquired. The importance of this point is underscored in d. above: There may well be two particular samples of glass with the same overall transmissivity, but one may have a higher transmissivity in the blue-green region.

II. Field Tests

Since we do not have any measurements of the acuity levels required to successfully execute the tasks of a cab controller, there is no point in performing detailed studies of visual acuity obtained with the various glass samples. Transmissivity data should be sufficient to determine which samples are unacceptable. Those samples which are not deemed unacceptable should then be used in a field preference test. The experimental procedure for such a test is outlined below.

A. Subjects

Controllers with substantial cab tower experience should be used in the test.

B. Apparatus

Those glass samples not deemed unacceptable on the basis of the transmissivity data should be tested in the mock-up cab tower.

C. Procedure

Subjects should be tested individually in the mockup. In both portions of the testing, the subjects should verbally indicate their preferences. The experimenter should record the data on the appropriate rating sheet.

Step 1: The glass samples, marked with an identifying code, should be placed at random positions in the mockup. When the subject enters the mockup, all the samples should be in place. The subject should then be permitted to walk through the mockup for 10-15 minutes and rate each of the glass samples. For this purpose a rating sheet must be supplied (see accompanying sample rating sheet).

Step 2: When the rating sheet has been completed and collected, all samples should be removed from their positions. The subject should be placed in front of one pane so that paired samples can be examined by him as they are placed in the pane. The experimenter should then place two samples, selected in a sequence determined by a table of random numbers, in the pane. The subject should be asked to indicate which of the two samples is "better." The non-preferred sample should be removed and replaced with another sample, again selected with reference to the random numbers table. Once

again, the subject should be asked to indicate which of the two samples is "better." The procedure should be repeated until all the samples have been pr sented.

It is recommended that the procedure outlined in Step 2 be run twice for each subject where possible. Every presentation sequence should be generated by independent reference to the random numbers table.

A sample preference sheet is attached.

Arrangements should be made to test subjects during daylight, at dawn or dusk, and at night. Weather conditions should be obtained from the NAFEC Weather Service: the data to be recorded are the visibility, in nautical miles, and the overall brightness condition (e.g., clear, overcast).

D. Data Analysis

The following should be computed for each glass sample:

1. Overall Percentage of Acceptable/Unacceptable Ratings (obtained in Step 1).

2. Percentage of Acceptable/Unacceptable Ratings under each viewing condition.

Random Sequence: 1-CL/CL, 2-FLS/FLC, 3-SO/FLC

SAMPLE

TOWER WINDOW GLASS: RATING SHEET

Time: Weather Conditions:

Instructions: Please examine each of the glass samples on display.

List the identifying code for each sample and indicate by a checkmark

whether you find the sample to be acceptable or unacceptable for cab use.

Position	Identifying Code	Acceptable	Unacceptable
1	CL/CL	X	
2	FLS/FLC		X
3	SO/FLC	X	
.	.		
.	.		
.	.		

Random Sequence: CL/CL, SO/FLC, FLS/FLC

SAMPLE

TOWER WINDOW GLASS: PREFERENCE SHEET

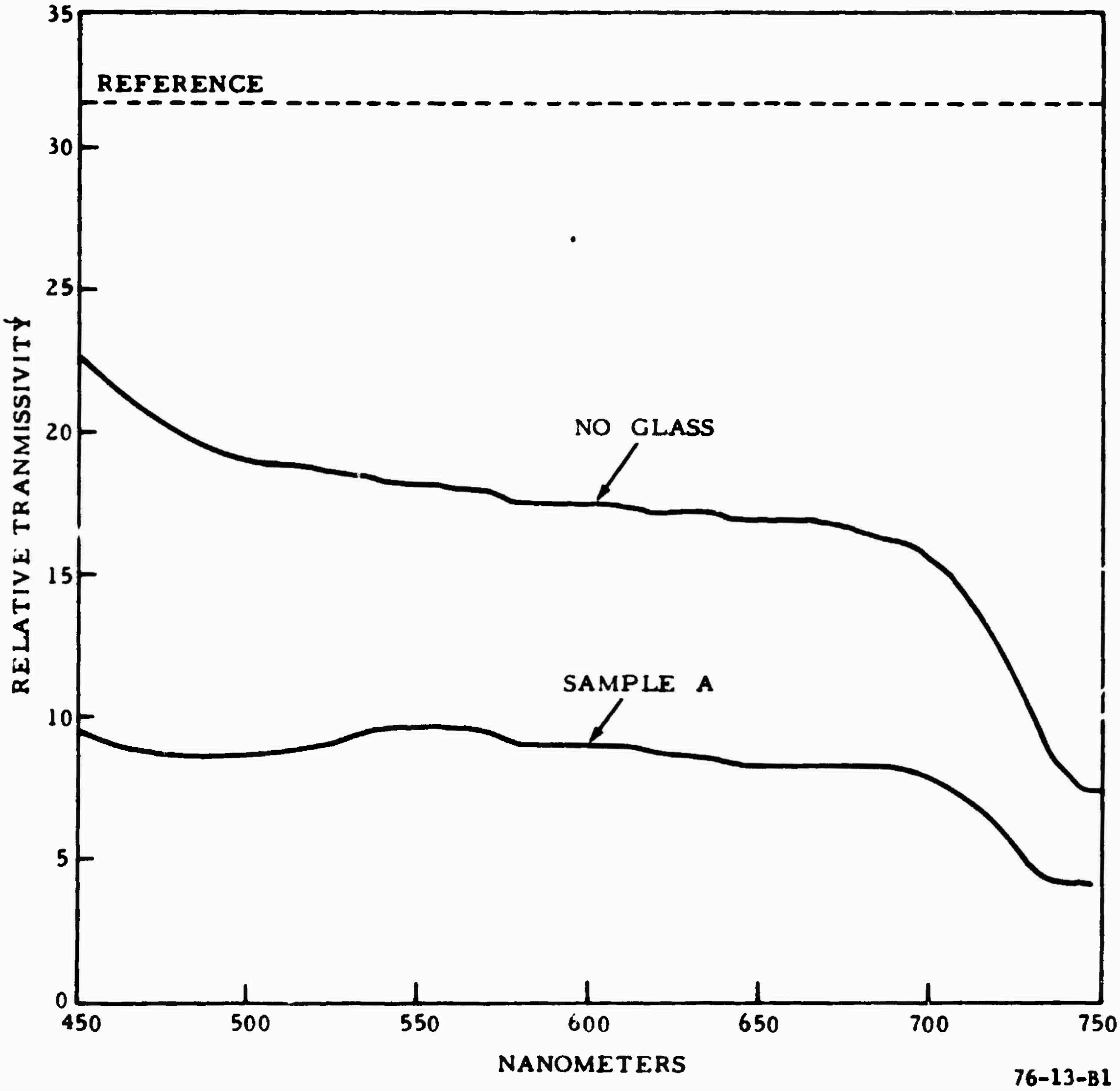
Run I: Time: Weather Conditions:

Identifying Codes	Preferred
CL/CL vs. SO/FLC	CL/CL
CL/CL vs. FLS/FLC	CL/CL
.	.
.	.
.	.

APPENDIX B

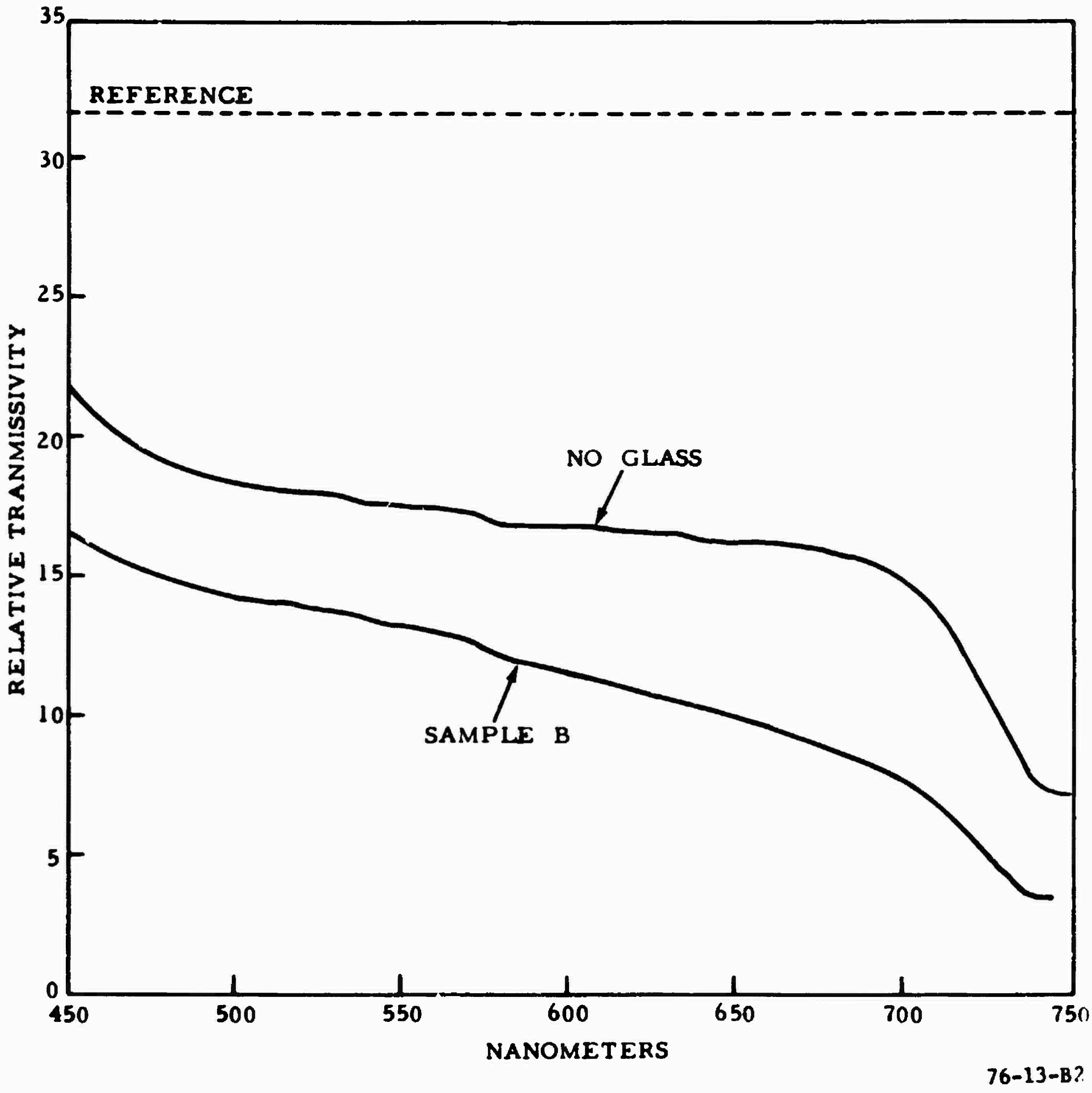
MEASURED SPECTRAL TRANSMISSIVITY CURVES

SAMPLE A - 1/4 INCH SOLAR BRONZE
AVERAGE DAYLIGHT - 20%
MEASURED AVERAGE - 48.6%
WEIGHTED AVERAGE - 50.7%



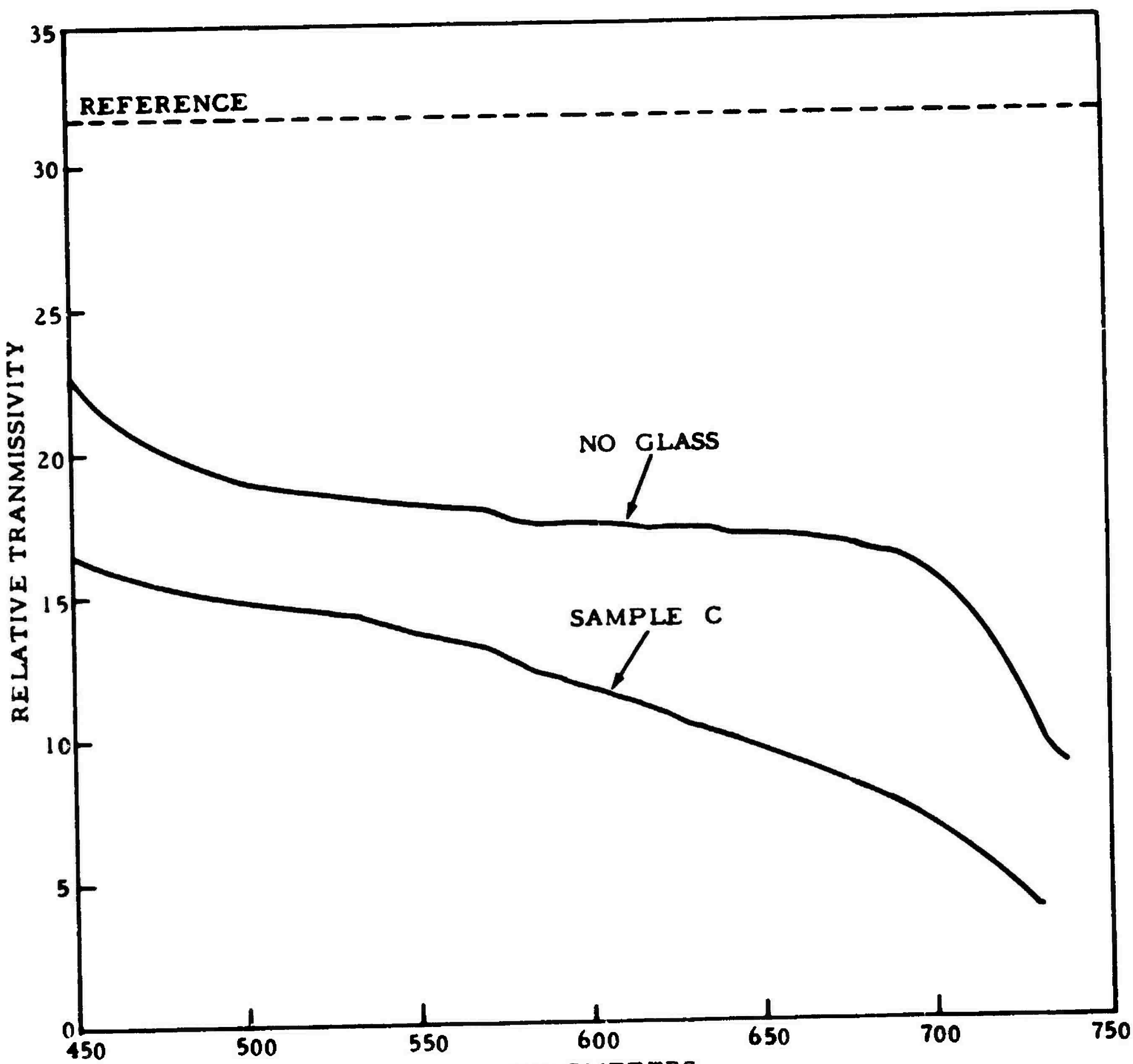
76-13-B1

SAMPLE B - 3/8 INCH CLEAR
AVERAGE DAYLIGHT - 83%
MEASURED AVERAGE - 70.9%
WEIGHTED AVERAGE - 73.0%



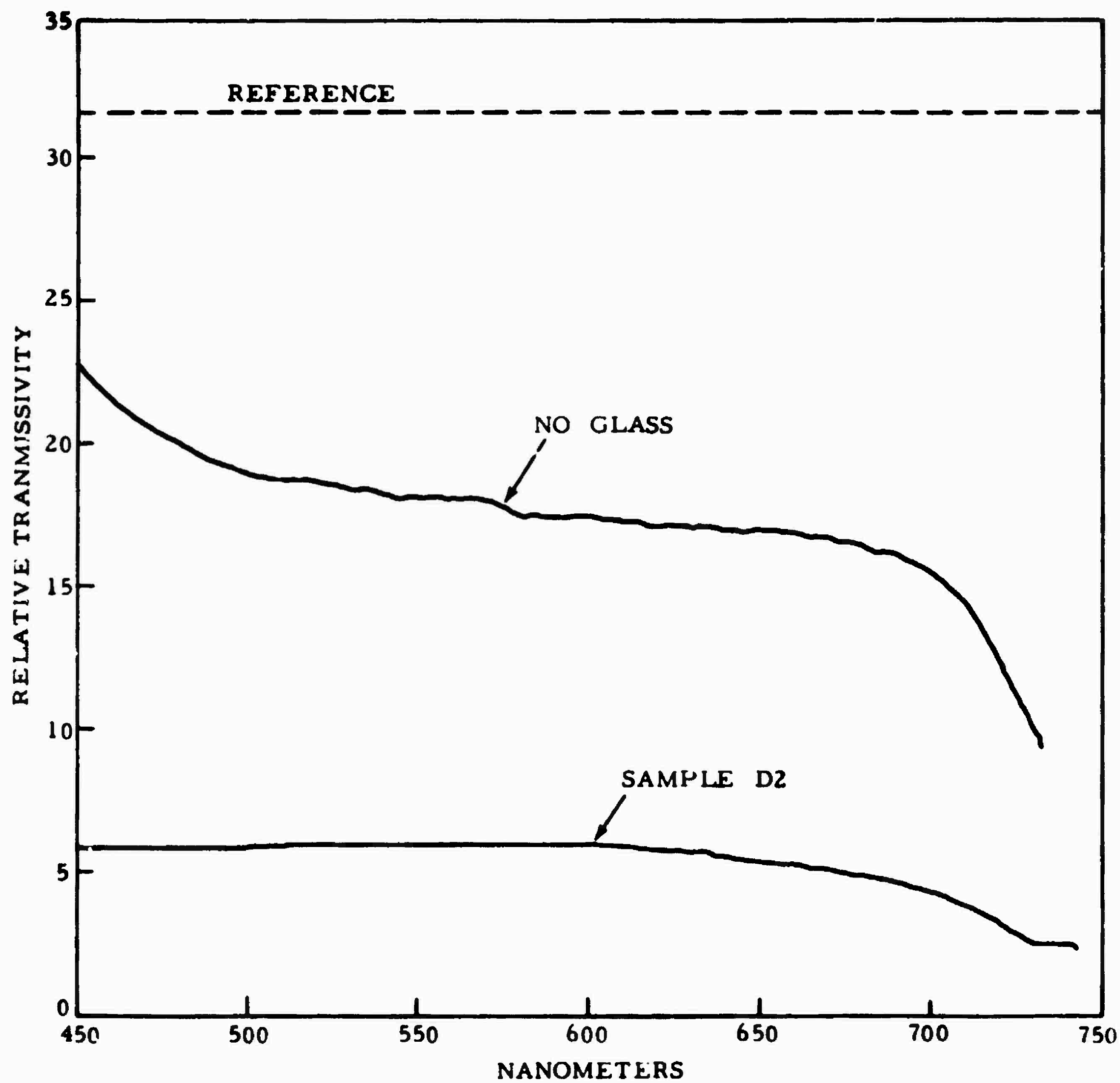
76-13-B2

SAMPLE C - 1/4 INCH SCLEX
AVERAGE DAYLIGHT - 65%
MEASURED AVERAGE - 68.6%
WEIGHTED AVERAGE - 82.1%

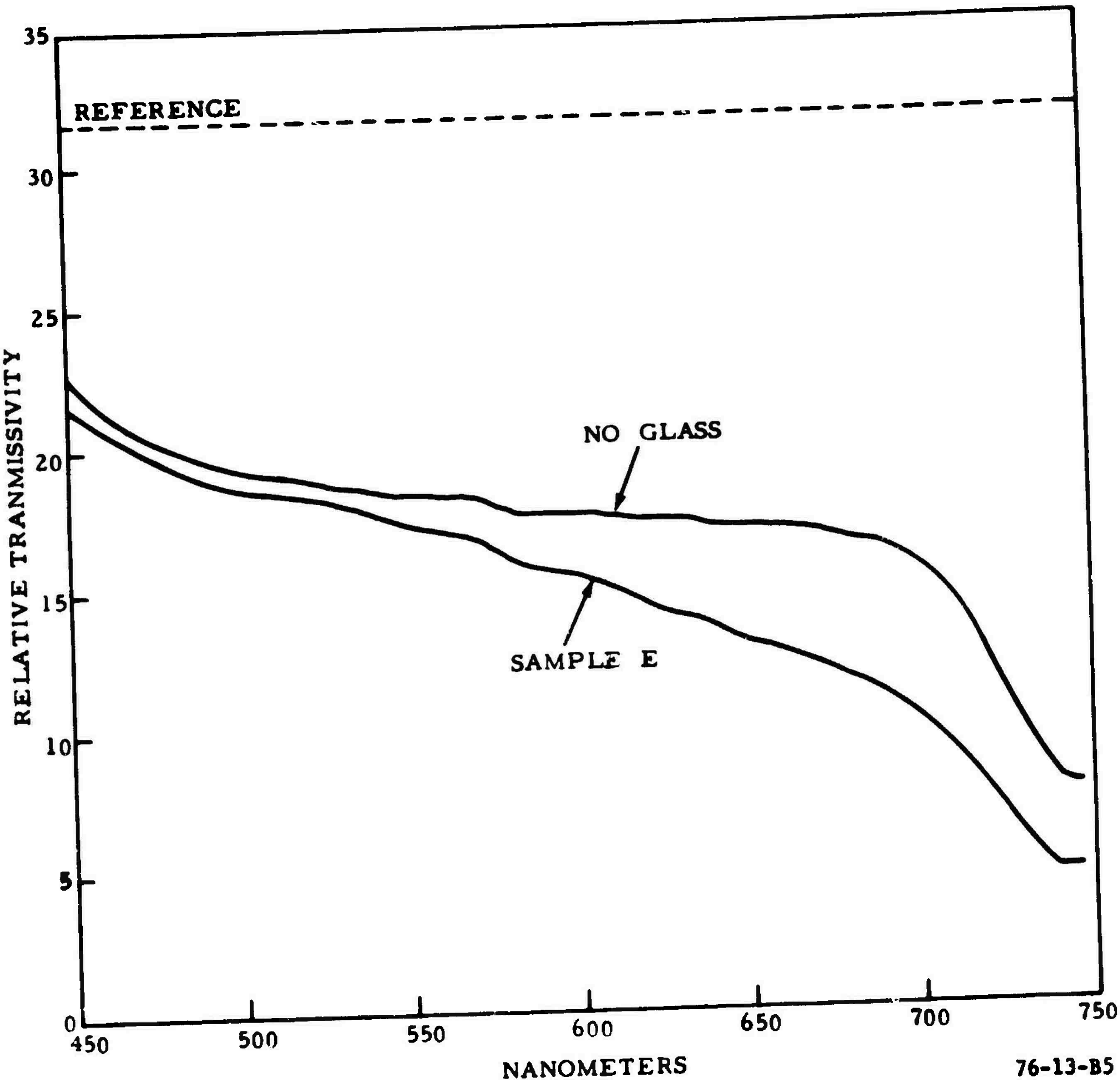


76-13-B3

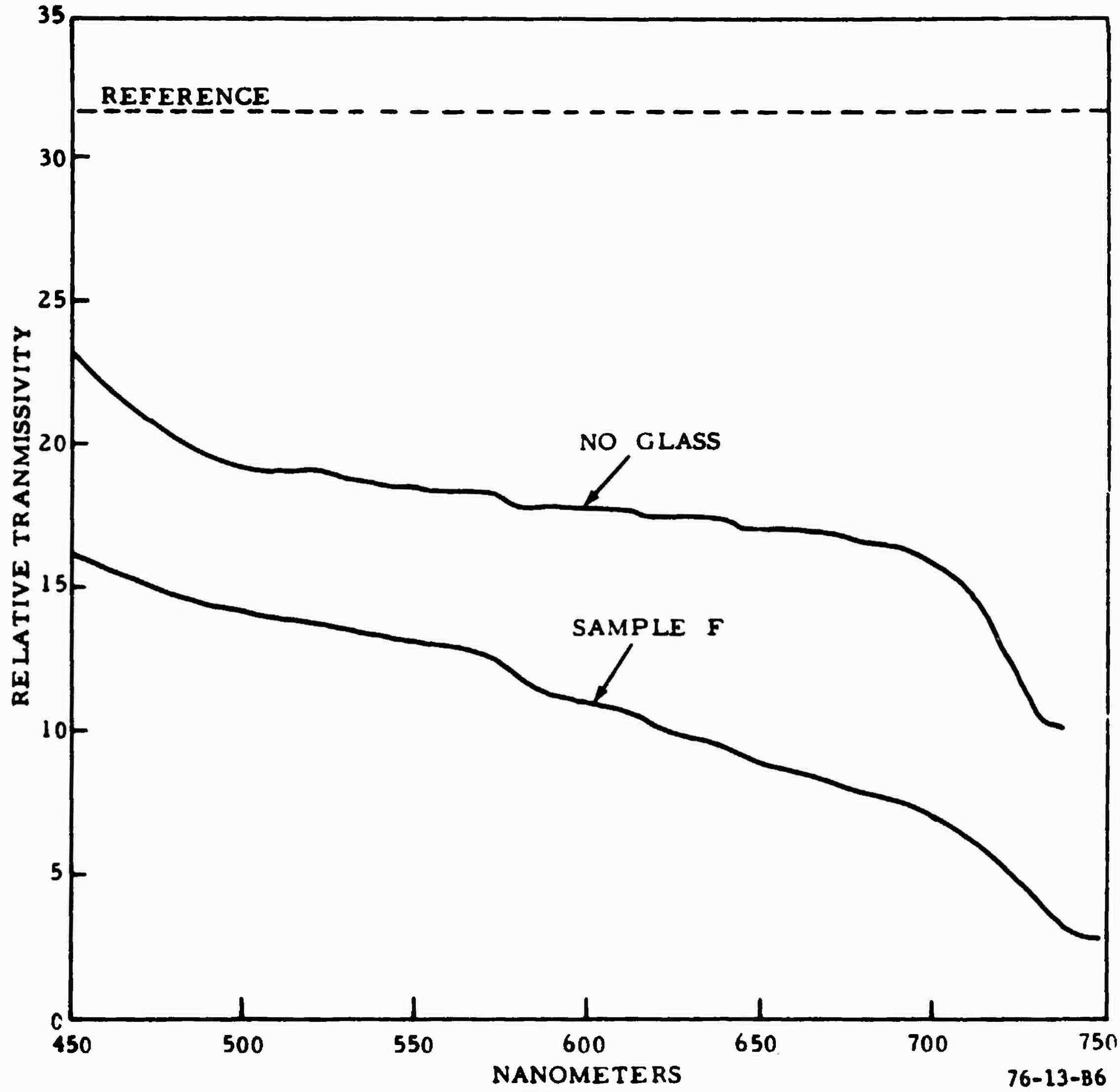
SAMPLE D - 1/4 INCH SOLAR COOL
AVERAGE DAYLIGHT - 35%
MEASURED AVERAGE - 31.3%
WEIGHTED AVERAGE - 32.7%



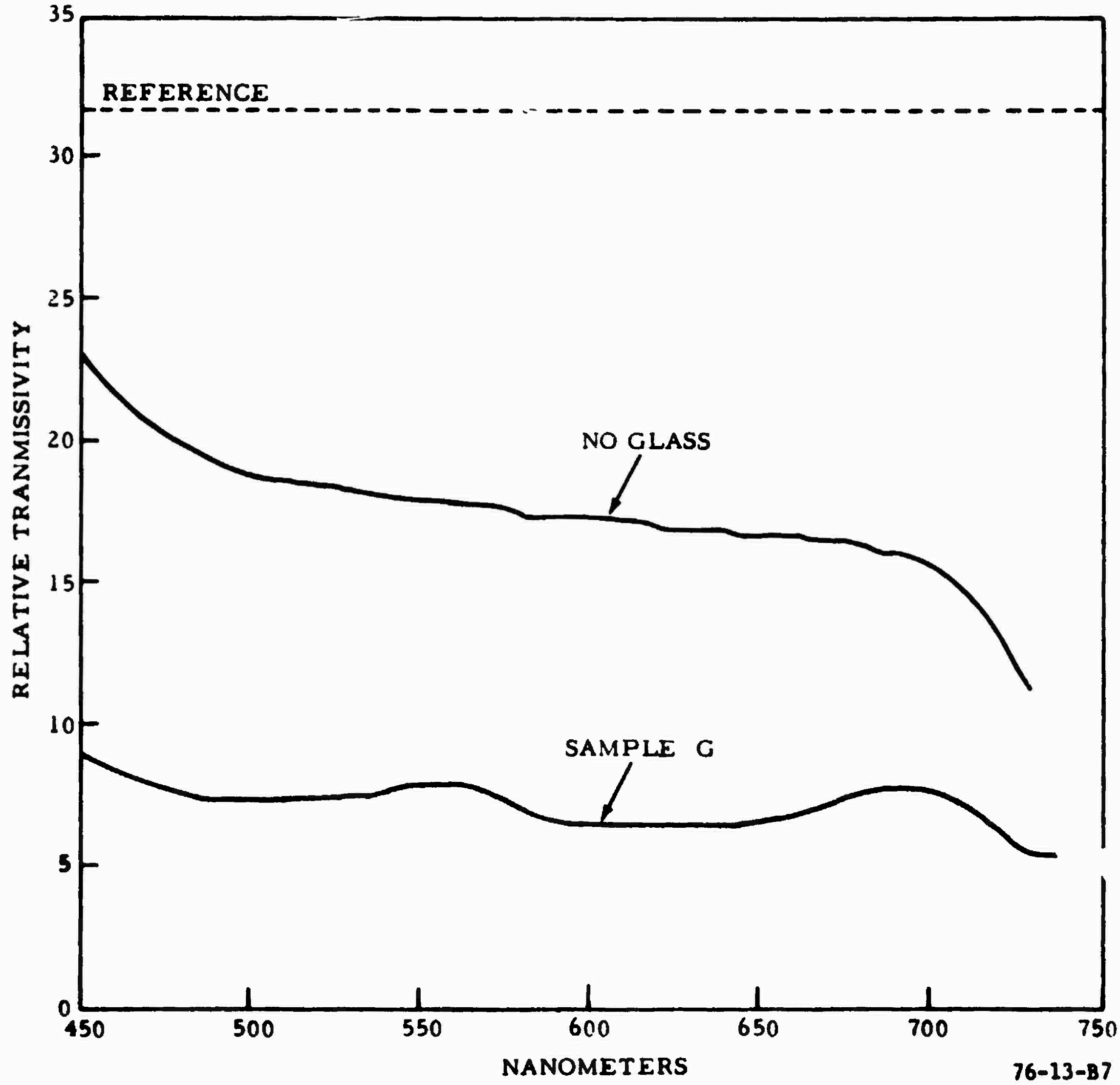
76-13-B4


35
30
25
20
15
10
5
0
REFERENCE
NO GLASS
SAMPLE E
RELATIVE TRANMISSIVITY
450
500
550
600
650
700
750
NANOMETERS
76-13-B5

SAMPLE F - 1/4 INCH HEAT ABSORBING
AVERAGE DAYLIGHT - 66%
MEASURED AVERAGE - 65.0%
WEIGHTED AVERAGE - 68.0%



SAMPLE G - 1/4 INCH GRAY
AVERAGE DAYLIGHT - 39%
MEASURED AVERAGE - 40.0%
WEIGHTED AVERAGE - 40.5%



APPENDIX C

RELATIVE VISUAL SENSITIVITY OF VARIOUS WAVELENGTHS OF LIGHT (DAYLIGHT ADAPTATION)

GAMMA SCIENTIFIC, INCORPORATED SAN DIEGO, CALIFORNIA

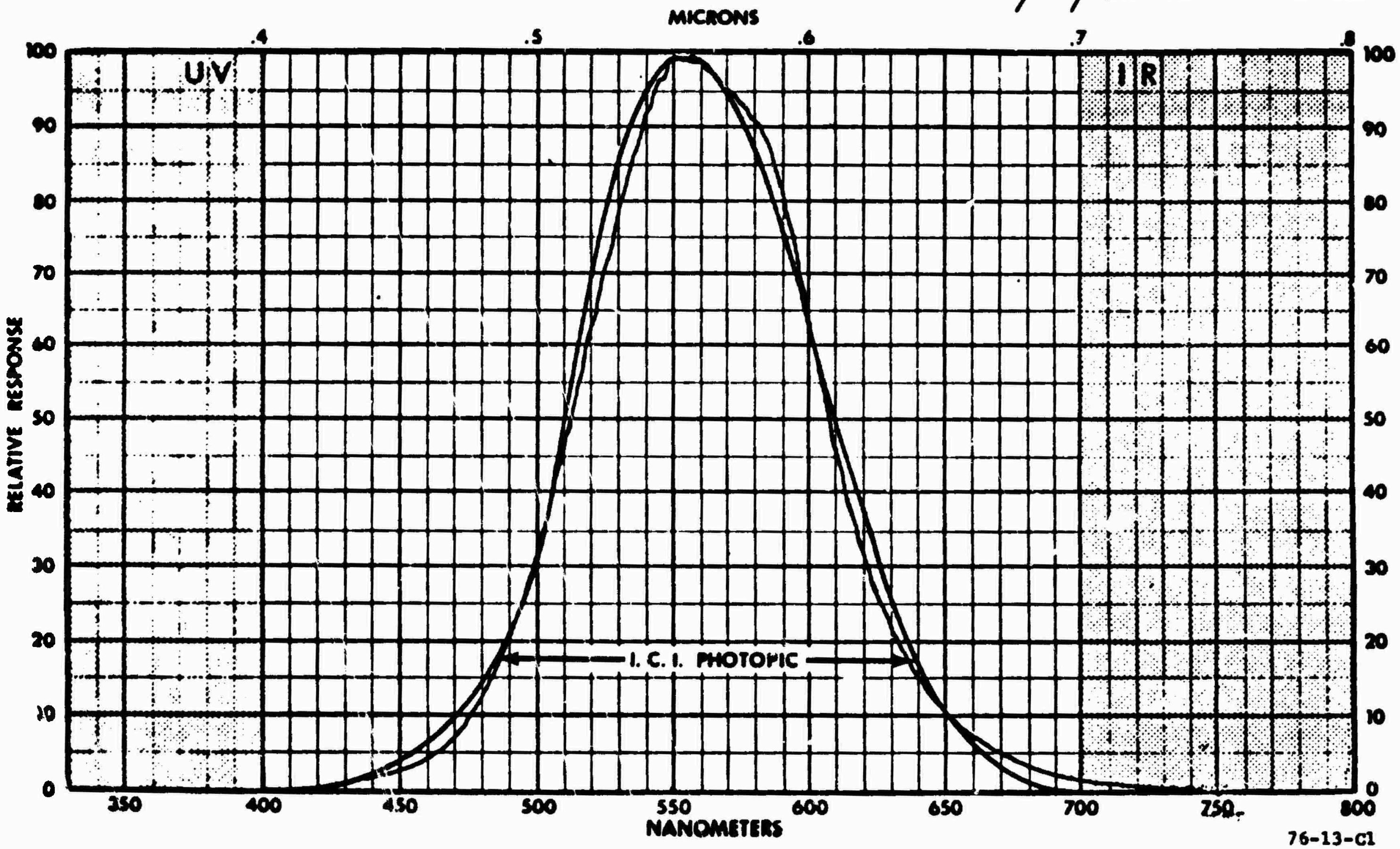
FAA 4/71 w/ probe

SPECTRAL CHARACTERISTICS OF MODEL 2020 SERIAL NUMBER 870 NORMALIZED ■

PHOTOMULTIPLIER TUBE TYPE PM-2 SERIAL NUMBER 1743 WITH PHOTOPIC CORRECTION

FILTER MODEL ______ NOTES: RAY with fiber optic probe

SOURCE: GAMMA SCIENTIFIC CONSTANT OUTPUT MONOCHROMATOR DATE: 4/21/71 BY: GD



76-13-C1

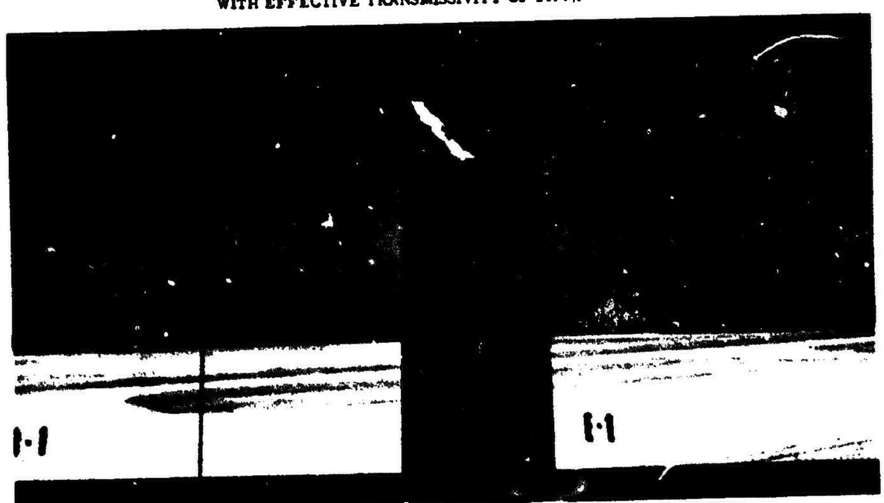
APPENDIX D

COLOR PHOTOGRAPHS THROUGH SAMPLE WINDOWS

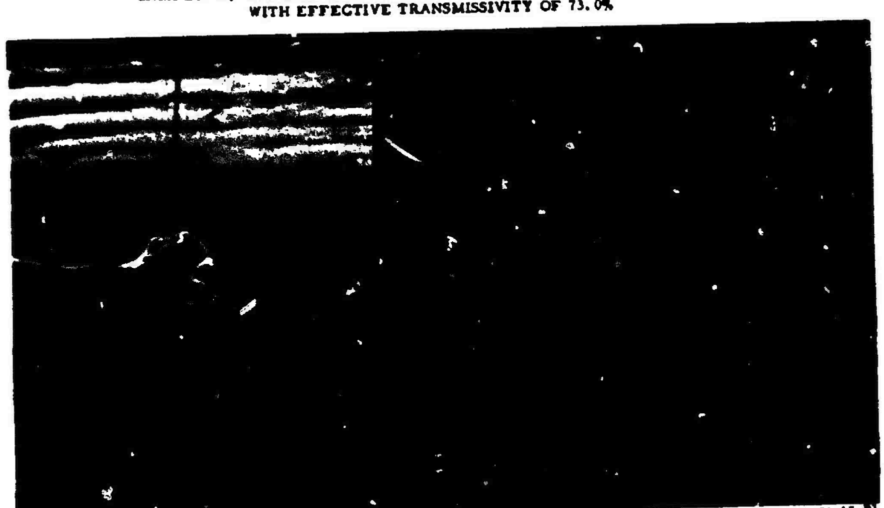
Sample E, 91.7-percent transmissivity, is on the right in each of the six photographs. The sample identified in the legend is always on the left-hand side.

NOTE: The color illustration showing Sample D is considerably exaggerated in pictorially displaying actual transmissivity. While it has a much lower transmissivity level than any other sample, it is still possible to see details on the field adequately under bright daylight conditions.

SAMPLE A. 1/4-INCH SOLAR BRONZE, 1/2-INCH AIR SPACE, 1/4-INCH CLEAR
WITH EFFECTIVE TRANSMISSIVITY OF 50.7%

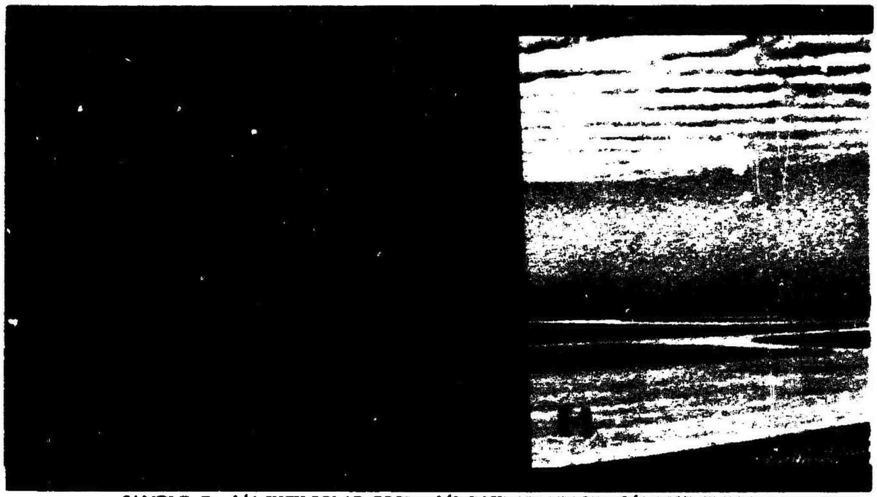


SAMPLE B. 3/8-INCH CLEAR, 1/2-INCH AIR SPACE, 3/8-INCH CLEAR
WITH EFFECTIVE TRANSMISSIVITY OF 73.0%



76-13-61

SAMPLE C. 1/4-INCH SOLEX, 1/2-INCH AIR SPACE, 1/4-INCH CLEAR
WITH EFFECTIVE TRANSMISSIVITY OF 82.1%



SAMPLE D, 1/4-INCH SOLAR COOL, 1/2-INCH AIR SPACE, 1/4-INCH CLEAR WITH EFFECTIVE TRANSMISSIVITY OF 32.7%

SAMPLE F, 1/4-INCH HEAT ABSORBING, 1/2-INCH AIR SPACE, 1/4-INCH CLEAR, WITH EFFECTIVE TRANSMISSIVITY OF 68.8%

SAMPLE G, 1/4-INCH GRAY, 1/2-INCH AIR SPACE, 1/4-INCH CLEAR WITH EFFECTIVE TRANSMISSIVITY OF 40.9%

76-13-D2

APPENDIX E

QUESTIONNAIRE USED FOR CONTROLLER RATINGS OF GLASS SAMPLES

AIR TRAFFIC CONTROL TOWER CAB GLASS EVALUATION SHEET

____________________ (observer's name)   date ___/___/74   TIME start ___:___ finish ___:___

CONTROLLER EVALUATION Look at the seven glass samples in the tower cab and make observations around the airport as you would if you were controlling traffic from the tower. After you have looked at all the samples, rate each one considering whether it helps or hinders the controllers' visual task UNDER PRESENT WEATHER AND LIGHTING CONDITIONS. Please record any comments you may have about the glass or the testing situation.

					COMMENTS
#1.	POOR ( )	FAIR ( )	GOOD ( )	VERY GOOD ( )	
#2.	POOR ( )	FAIR ( )	GOOD ( )	VERY GOOD ( )	
#3.	POOR ( )	FAIR ( )	GOOD ( )	VERY GOOD ( )	
#4.	POOR ( )	FAIR ( )	GOOD ( )	VERY GOOD ( )	
#5.	POOR ( )	FAIR ( )	GOOD ( )	VERY GOOD ( )	
#6.	POOR ( )	FAIR ( )	GOOD ( )	VERY GOOD ( )	
#7.	POOR ( )	FAIR ( )	GOOD ( )	VERY GOOD ( )	

COMMENTS:

NA FORM 9800-1 OT (10-74)   Use Expires 2 1 75

APPENDIX F

PHOTOGRAPHS SHOWING INTERNAL REFLECTION IN SOME SAMPLES AT NIGHT

PPG SOLAR COOL/FLOAT CLEAR (D)

PPG 3/4" CLEAR FLOAT (E)

76-0773